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EPA-SUPPORTED WASTELOAD ALLOCATION MODELS

by

Thomas O. Barnwell, Jr.,* and D. King Boynton**

*Environmental Research Laboratory
U.S. Environmental Protection Agency
Athens, Georgia 30613
**Office of Water
U.S. Environmental Protection Agency
Washington, DC 20460

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA. 30613

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EPA Supported Wasteload Allocation Models

Thomas O. Barnwell, Jr.[1], Member, ASCE
D. King Boynton[2]

ABSTRACT

Modeling is increasingly becoming a part of the Wasteload Allocation Process. The U S EPA provides guidance, technical training and computer software in support of this program. This paper reviews the support available to modelers through the Wasteload Allocation Section of EPA's Office of Water Regulation and Standards and through the Center for Water Quality Modeling of EPA's Office of Research and Development. The paper also looks to the future of water quality modeling and the prospect for principles from Artificial Intelligence increasing the accessibility of these tools to practitioners.

INTRODUCTION

As part of the national effort to implement the Clean Water Act, water quality planners and managers in the United States have increasingly used mathematical models to analyze water quality problems. These models are used in conducting evaluations of waste loads from point and nonpoint sources and in pollutant exposure assessments. To encourage the wider application of these techniques, EPA supports two activities that provide technical assistance and methodologies in support of wasteload allocation.

OFFICE OF WATER REGULATION AND STANDARDS

The Wasteload Allocation Section of the Monitoring and Data Support Division in EPA's Office of Water Regulation and Standards provides national policy and guidance for the program and provides technical training and assistance in support of Wasteload Allocation. These guidance documents, part of the **Technical Guidance Manual for Performing Wasteload Allocations,** are summarized in Table 1 and discussed below. The documents are available by writing:

Wasteload Allocation Section (WH-553)
Monitoring and Data Support Division
U S EPA
Washington, DC 20640.

A monthly newsletter is circulated that gives the status of the guidance documents and discusses other wasteload allocation related subjects.

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1. Environmental Research Laboratory, U S EPA, Athens, GA 30613
2. Monitoring and Data Support Division, U S EPA, Washington, DC 20460

Table 1. Summary of Wasteload Allocation Guidance Status (March 1985)

BOOK		CHAPTERS	STATUS
I.	The TMDL Process		In Preparation
II.	Streams and Rivers	BOD/DO Impacts	Available
		Nutrients/Eutrophication	Available
		Toxic Substances	Available
III.	Estuaries	BOD/DO Impacts	In Review
		Nutrients/Eutrophication	In Review
		Toxic Substances	In Review
IV.	Lakes and Impoundments	BOD/DO Impacts	In Planning
		Nutrients/Eutrophication	Available
		Toxic Substances	In Preparation
V.	Design Conditions	Stream Flow	In Review
		Temperature	In Review
		pH	In Review
		Effluent Flow	In Preparation
		Rate Constants	In Planning
VI.	Permit Averaging		Available
VII.	Screening Manual	Toxic Organics/ Conventional Pollutants	Available
		Toxic Metals	In Review
VIII.	Innovative Wasteload Allocations		In Review
IX.	Toxics Control		In Review
X.	Program Guidance		In Review

Book I. The TMDL Process, currently in planning, will provide a general description of the TMDL (Total Maximum Daily Load) process for those waters where technology based effluent limitations are insufficient to protect and maintain the designated water uses. This document will describe the steps of the process and show how they interrelate.

Book II. Wasteload Allocations for Streams and Rivers consists of three chapters. Chapter 1 provides methods for establishing BOD and ammonia wasteload allocations, chapter 2 provides methods for establishing nutrient wasteload allocations, and chapter 3 provides methods for toxic substances. These three chapters are currently available.

Book III. Wasteload Allocations for Estuaries also consists of three chapters that parallel the subject matter for streams and rivers. These three chapters are currently under review.

Book IV. Wasteload Allocations for Lakes and Impoundments also parallels the streams and rivers' subject matter. Chapter 2, nutrient wasteload allocations, is currently available, and chapter 3, toxic substances, is in preparation.

Book V. Design Conditions develops rational methods for selecting design conditions for each of the major environmental and effluent variables involved in steady state modeling. These variables include stream flow, temperature, pH, effluent flow, concentration/loading, and rate constants. Chapter 1 (stream flow) is in the final revision stage and will provide a method for establishing a stream design flow for water quality modeling based upon the acute and chronic toxicity of the pollutant and the low flow variability of the receiving stream. Chapters 2 (temperature) and 3 (pH) are also under review and will provide methods for establishing design conditions that represent the stream's critical event. Site-specific design conditions are developed through a simulation modeling approach. Chapter 4 (effluent flow, concentration and loading) is in the early stages of preparation and will include techniques to develop normalized curves for these variables on a monthly and seasonal basis. The normalization will be done with respect to the POTW (Publicly Owned Treatment Works) design flow, concentration and loading. Chapter 5 is in planning and will include statistical techniques for making the best water quality-based choice of various rate constants.

Book VI. Permit Averaging Periods, currently available, provides a rational basis for selecting the most appropriate NPDES permit averaging period (1-, 7-, or 30-day) for any industrial or POTW effluent. The technique considers the site-specific variability of receiving stream and the effluent.

Book VII. Screening Manual (14) , also available, provides desk-top analysis techniques for use with hand-held calculators for assessing the loading and fate of both conventional (temperature, BOD/DO, nutrients and sediment) and toxic pollutants (from the 129 priority pollutants list) in streams, impoundments and estuaries. An addendum describing procedures for metals is in the final stages of review.

Book VII. Innovative Permits, now in review, provides guidance for the issuance of innovative permits based on sound wasteload allocations. It presents the principles behind standard and innovative permits and emphasizes seasonal permit limits for BOD and nitrogen.

Book IX. Technical Support Document for Water Quality-Based Toxics Control, now under review, provides procedural recommendations for identifying, analyzing, and controlling adverse water quality impacts caused by discharge of toxic pollutants. This document supports implementation of the U S EPA's national policy for the development of water quality-based permit limitations for toxic pollutants (16).

Book X. Guidance for State Water Monitoring and Wasteload Allocation Programs, to be available in early summer 1985, defines the process that the States and EPA Regional Offices use in developing monitoring and wasteload allocations under sections 106 and 303(d) of the Federal Water Pollution Control Act.

The Monitoring and Data Support Division has also sponsored technical seminars for State and EPA Regional Office personnel. These seminars have presented basic modeling principles, theory, and case studies for BOD/DO and toxic pollutant modeling. Workshops on implementation of Book IX, the Technical Support Document for Water Quality-Based Toxics Control, have also been conducted. These workshops included recommendations on how to conduct near- and farfield modeling for individual toxicants and whole effluent toxicity. Both steady-state and dynamic modeling techniques were discussed. By September 1985, three workshops will be conducted on toxic wasteload allocation models that have been successfully calibrated for rivers, lakes and estuaries. Model theory and structure will be described and example model applications will be presented. Future seminars will deal with permit averaging and design conditions, innovative wasteload allocations, and estuary modeling.

OFFICE OF RESEARCH AND DEVELOPMENT

EPA's Office of Research and Development established the Center for Water Quality Modeling to provide a focal point for water quality modeling activities. The Center for Water Quality Modeling is located at EPA's Environmental Research Laboratory in Athens, Ga, which has long been involved in the development and application of mathematical models that predict the transport and fate of water pollutants. For selected water quality and pollutant loading models, the Center provides a central file and distribution point for computer programs and documentation. In addition, the Center sponsors workshops and seminars that provide both generalized training in the use of models and specific instruction in the application of individual simulation techniques.

The modeling packages currently available through the Center were selected from many candidate models by experienced users in EPA regulatory and regional offices and by the Center staff. Selection criteria included model utility and effectiveness, availability of adequate documentation, degree of acceptance and application by users, and the Center staff's experience with the software. A wide range of analysis techniques is provided, ranging from simple desk-top techniques suitable for screening analysis through computerized steady-state models to sophisticated, state-of-the-art continuous simulation models for detailed planning. Modeling packages currently supported by the Center are:

Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants (14) -- a collection of formulas, tables and graphs that planners can use for preliminary assessment of surface water quality in large river basins. These desk-top procedures are appropriate for hand calculators. The manual includes a discussion of the environmental chemistry of synthetic organic chemicals and metals; a chapter on waste source estimation techniques; and simple methods for assessment of pollutant fate and transport in rivers, lakes and estuaries. Stream analysis techniques include conservative substances, water temperature, biochemical oxygen demand, dissolved oxygen, total suspended solids, coliform bacteria, nutrients, and toxic organic chemicals. Lake analysis procedures include thermal stratifi-

cation, sediment accumulation, toxic organic chemicals, phosphorus budget, eutrophication potential, and hypolimnion dissolved oxygen. Estuarine analyses include estuarine classification, temperature, biochemical oxygen demand, dissolved oxygen, turbidity, sediment accumulation, and non-conservative substances. This manual has been adopted as Book IX of the agency's National Wasteload Allocation Guidance.

Exposure Analysis Modeling System (EXAMS) (2) -- a steady-state model designed for rapid evaluation of the behavior of synthetic organic chemicals in aquatic ecosystems. Starting from a description of the chemistry of a toxicant and relevant transport and physical-chemical characteristics of the ecosystem, EXAMS computes exposure, the ultimate expected environmental concentrations resulting from a long-term steady pattern of pollutant loadings; fate, the distribution of the chemical in the environment and the fraction of the loadings consumed by each transport and transformation process; and persistence, the time required for effective purification of the system once the loadings cease. EXAMS is an interactive program and allows the user to store the properties of chemicals and ecosystems, modify the characteristics of either via simple English-like commands, and conduct rapid, efficient evaluations of the probable fate of chemicals.

MEXAMS is an extension of the EXAMS model for heavy metals that incorporates **MINTEQ**, a thermodynamic equilibrium model that computes aqueous speciation, adsorption and precipitation/dissolution of solid phases (9). This model permits the user to examine the equilibrium distribution of heavy metals along with transport and fate in various aquatic systems. This information is important because different species of a metal may cause differing biological effects.

Stream Water Quality Model QUAL-II (15) -- a steady-state model for conventional pollutants in branching streams and well-mixed lakes. It includes conservative substances, temperature, coliform bacteria, biochemical oxygen demand, dissolved oxygen, nitrogen, phosphorus and algae. QUAL-II is widely used for waste load allocation and permiting in the United States and other countries. It has a 15 year history of application and is a proven, effective analysis tool.

Storm Water Management Model (SWMM) (11) -- a comprehensive model for simulation of urban runoff quantity and quality. All aspects of the urban hydrologic and quality cycles are simulated including surface runoff, transport through the drainage network, and storage and treatment (including cost). Alternative techniques are available for simulation of sewer systems -- a kinematic wave procedure for most problem assessments and a full-equation routing method for surcharged systems. SWMM can be used both for single-event and continuous simulation. It has been used in a planning context as well as for detailed design studies. SWMM also has a long history of use in the United States and Canada for urban drainage assessment and design.

Agricultural Runoff Management (ARM) (5) and **Non Point Source (NPS)** (6) -- techniques for assessing agricultural and urban nonpoint source loadings. The models use the Stanford Watershed Model for the water balance and extend it to the assessment of nonpoint source pollution from agricultural and urban areas. ARM can be used to study

pollutants from agricultural lands such as sediment, nutrients and pesticides and includes detailed process descriptions for nutrient and pesticide fate on the land surface. NPS contains simpler algorithms and can be used on both urban and agricultural lands.

Hydrological Simulation Program - FORTRAN (HSPF) (12) -- a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates the watershed-scale ARM and NPS models into a basin-scale analysis framework that includes fate and transport in stream channels. Simply put, the model uses such information as the time history of rainfall, temperature, and solar radiation; land surface characteristics, use patterns and soil properties; and land management practices to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. The program takes these results, along with information about the stream network and simulates instream processes to produce a time history of water quantity and quality at any point in a watershed -- the inflow to a lake, for example. HSPF includes an internal data base management system to process the large amounts of simulation input and output. A user-friendly editor to aid in developing input for the program is also available (13) as well as a comprehensive application guide (8).

Water Analysis Simulation Program (WASP) (4) and its extension to toxic contaminants, **TOXIWASP** (1) -- a generalized modeling framework for contaminant fate and transport in surface waters. Based on the flexible compartment modeling approach, WASP can be applied in one, two, or three dimensions. A variety of water quality problems can be addressed with the selection of appropriate kinetic subroutines that may either be selected from a library or written by the user. WASP is designed to permit easy substitution of user-written routines into the program structure. Problems that have been studied using WASP include biochemical oxygen demand-dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and toxic chemical movement. TOXIWASP combines a kinetic structure adapted from EXAMS with the WASP transport structure and simple sediment balance algorithms to predict dissolved and sorbed chemical concentrations in the bed and overlying waters. WASP has been used in the Great Lakes and the Potomac estuary to assess eutrophication problems. TOXIWASP has been applied in Mississippi and in the Delaware estuary to examine fate and transport of toxic contaminants. **WASTOX** (3) is similar to TOXIWASP in that it includes additions to WASP to assess the fate and transport of toxic chemicals in the environment. WASTOX is also being used as a research tool to investigate the fate of chemicals in the aquatic food chain.

ANNIE (13) -- an interactive model input editor under development in conjunction with the United States Geological Survey. ANNIE is a FORTRAN program designed for mini- and microcomputers to help the user interactively create, check, and update input to hydrologic and water quality models. For models that require access to data bases, ANNIE can be used to reformat, store, list, update and plot these data. Each model has an information file that is used to display questions

and check the responses against acceptable values. When all input has been prepared, the model is then submitted for processing. Eventually, ANNIE will also help the user interpret model output by printing, plotting and statistically analyzing the output. ANNIE is a general software package that can be applied to any model. It was first applied to EPA's HSPF water quality model (see above) and two USGS rainfall/runoff models.

Further information on the software described above can be obtained by writing:

Center for Water Quality Modeling
Environmental Research Laboratory
U S EPA
Athens, GA 30613

The Center also maintains a mailing list of persons interested in the subject, sponsors a Users Group that meets twice a year, and sponsors periodic training on supported software.

APPLICATIONS OF ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS TO MODELING

To further the usability of these computerized models, the Athens Environmental Research Laboratory is beginning a research program in the application of artificial intelligence/expert systems technology to environmental modeling. Preliminary investigations have shown this technology to be very promising in enhancing the ease-of-use of environmental models (10).

Modeling, in its computerized form, is becoming a key component of decision-making in EPA. The problems facing the agency increasingly involve more complex interactions between elements of the environment. Large, multi-media modeling systems must be built to understand these interactions. Artificial intelligence is an important methodology that can assist in building, using, and interpreting these models. Several of the concepts from artificial intelligence can be of benefit to environmental modeling. They include:

* A different perspective on decision-making.
* Programming languages that can reason as well as compute.
* Improved man-machine interaction.

There is a fundamental dichotomy in modeling and regulation. Modeling is directed at predicting the consequence of an action, e.g., the environmental concentration resulting from a waste discharge. Regulation, however, focuses on limiting the range of actions in order to protect the environment from adverse consequences. Regulation can be directed at either the environmental concentration or the waste discharge. Traditionally, technological standards have been set on the waste discharge but this regulatory strategy must be extremely conservative to be protective. To be more efficient and cost-effective, regulation must be directed at site-specific environmental concentrations. However, this strategy requires that an inverse problem be solved, i.e., the regulator must infer an allowable waste discharge from a target environmental concentration. In a system with complex

environmental interactions and multiple waste sources, this problem is nontrivial and the solution is usually not unique. Problem-solving in this context can be viewed as a search for optimal solutions and notions from Artificial Intelligence about search spaces and search strategies have important implications to efficient decision making.

Modeling, as currently practiced, uses a rigid algorithmic language such as FORTRAN as the fundamental way of representing knowledge. The concept of the knowledge base or knowledge representation in Artificial Intelligence is much broader and includes ways to deal with incomplete or uncertain data. Knowledge can typically be divided into two classes: factual or causal knowledge and empirical associations or rules. For example, an algorithmic processor deals with causal relationships and may ask for a single value for an input variable. A knowledge-based expert system will allow input of an upper and lower bound for the variable as well as the degree of certainty in that variable. The process by which an experienced modeler evaluates parameter values can also be made part of the model.

In artificial intelligence methodology, premise-action rules are selected by a knowledge processor, or inference engine. The processor also has the capability to explain why particular rules are chosen and used. This explanation feature is important in dealing with ill-structured or ill-defined problems because it documents the system's reasoning process. This feature will be extremely important in a regulatory framework that makes extensive use of computer technology because it clearly presents and documents the information used in making a decision.

Large, complex models require extensive human interaction for their successful implementation. A major barrier to this interaction is the paucity of most computer languages compared to natural languages. An expert system can act as an intelligent front end to a complex simulation model, relieving the user of the tedium of preparing rigidly formatted model input and advising the user on selection of appropriate parameter values, especially under conditions of uncertainty. Such a system might include alternate parameter estimation techniques and provide advice on the estimate with which the system has highest confidence. An expert system with these capabilities has been developed in prototype form for 16 important hydrologic parameters in EPA's Hydrologic Simulation Program - FORTRAN (HSPF) (10). The availibility of a knowledge-based expert system containing the experience and expertise of model developers and skilled users would be of enormous benefit to those skilled in the physical and biological sciences but less skilled in the art of interacting with the computer.

The addition of extended modeling capabilities such as uncertainty and sensitivity analysis would facilitate model calibration and verification. Inclusion of this capability in models will be facilitated by an expert system that can aid the user both in the model calibration/ validation stage and in the model interpretation and decision making process.

As mentioned above, EPA is cooperating with the United States Geological Survey in the development of ANNIE, an input data preparation system and data base for hydrologic models that includes rudimentary artificial intelligence concepts. This system has the potential to provide basic public domain tools that can be used to further implement artificial intelligence concepts in modeling. This system now aids model input preparation and will increase access to models for many users. Software design for a general hydrologic model data base is underway. However, an important part of modeling that has not yet been addressed by these "intelligent" systems is the interpretation of model output.

It is expected that most of the developmental work specific to environmental modeling will focus on model output interpretation and completing the feedback loop for the calibration/verification process. Preparing model input is conceptually analogous to data base preparation and it is expected that the literature will be very rich in these concepts because of their commercial utility. One concept that will be considered is an intelligent interface that can "learn" a user's jargon and preferences for model input. Such an interface could make a user much more comfortable when first using a new model. Much of the effort in learning a new computer program goes into learning the syntax and input formats preferred by the software. This part of the learning curve, at least, might be put on the software and not on the user.

Methods for interpretation of model output and the calibration/verification process, however, are not as well developed. To the extent that this process involves optimization, the AI literature in pattern recognition may prove fruitfull but it is expected that this part of the project will involve considerable developmental work.

SUMMARY

In this paper, we have discussed the support available for waste-load allocation available from the U S EPA. This support ranges from general technical guidance available from the Office of Water Regulation and Standards to specific software available from the Athens Environmental Research Laboratory. We have also discussed prospective research using expert systems directed at improving the usability of this software.

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